Impact of Radio-Frequency Identification (RFID) Technologies on the Hospital Supply Chain: A Literature Review

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Abstract

Supply costs account for more than one-third of the average operating budget and constitute the second largest expenditure in hospitals. As hospitals have sought to reduce these costs, radio-frequency identification (RFID) technology has emerged as a solution. This study reviews existing literature to gauge the recent and potential impact and direction of the implementation of RFID in the hospital supply chain to determine current benefits and barriers of adoption. Findings show that the application of RFID to medical equipment and supplies tracking has resulted in efficiency increases in hospitals with lower costs and increased service quality. RFID technology can reduce costs, improve patient safety, and improve supply chain management effectiveness by increasing the ability to track and locate equipment, as well as monitoring theft prevention, distribution management, and patient billing. Despite ongoing RFID implementation in the hospital supply chain, barriers to widespread and rapid adoption include significant total expenditures, unclear return on investment, and competition with other strategic imperatives.

Keywords: RFID, hospital, supply chain, costs, assets, mobile equipment

Introduction

The US national health expenditure is expected to reach $4.2 trillion with hospital expenses accounting for $760.6 billion or 18.9 percent of the GDP by 2019.[1] Health Information technology (HIT) systems are now being considered as a potential means to reduce hospital costs and improve clinical performance.[2] In the near future, many HIT systems are expected to be implemented as result of the mandate of the Health Information Technology for Economic and Clinical Health (HITECH) Act, which is a part of the American Recovery and Reinvestment Act of 2009 (ARRA).[3]

Hospitals have begun to incorporate products to control and evaluate equipment that moves in and out of the organization through the use of radio-frequency identification (RFID), a wireless system utilizing radio-frequency electromagnetic fields to obtain data for tracking and identifying items. RFID tags enable scanning of an item or device so that its contents, location, manufacture date, order numbers, and shipping data can be transmitted to the correct person for use within the company.[4] Even though adoption of this technology has been slow, several areas within healthcare have started using RFID. For example, pharmaceutical companies use RFID to track prescriptions for clinical trials, track counterfeit products, and manage inventory. In hospitals, RFID is used to track expensive medical equipment, patients, blood, and inventory.[5]

Because supply costs are the second largest expenditure in hospitals, accounting for about 30 to 40 percent of the average hospital operating budget, careful and efficient control of supply costs is critical for a hospital's success.[6] In the hospital industry, the supply chain can be a complex system that requires the adequate flow of products and services in order to fulfill the needs of providers.[7]

The healthcare supply chain has been variously defined. According to the University of Maryland Medical System (2011), the healthcare supply chain is the life-cycle process for supplies, including the transportation from manufacturers to the point of use and reimbursement processes, whose purpose is to satisfy end-user requirements with products and service from multiple, linked suppliers.[8] A similar description by Schneller and Smeltzer (2006) defined the healthcare supply chain as the finances, information, and supplies involved in acquiring and moving goods and services from the supplier to the end user in order to enhance clinical outcomes and controlling costs.[9]

Several conditions and circumstances serve to increase hospital supply chain costs. Large amounts of expensive inventory, such as pacemakers, defibrillators, catheters, and implants, are used in operating rooms. However, the lack of visibility in the supply chain can result in lost, stolen, or misplaced equipment, driving up operational costs.[10] In 2004, lost and stolen equipment cost about $ 4,000 per bed, increasing to $8,000 when expenses incurred from out-of-place equipment were added.[11] Another significant cost driver is the universal complexity of the healthcare supply chain. Examples of unique challenges of the supply chain in hospitals are that products and medical devices used in procedures can be extremely expensive, inventory tracking can be highly difficult because of the urgency of medical procedures, and the demand of products required for surgery can be very unpredictable due to the diversity of patients' characteristics.[12]

The purpose of this study was to gauge the recent and potential impact and direction of the implementation of RFID in the hospital supply chain to determine current benefits of and barriers to adoption of this technology.

Methodology

The methodology for this study was a literature research and review of case studies. The approach for this research study followed systematic search steps and research framework utilized by Yao et al. (2010).[13] The use of that conceptual framework in the current study is appropriate because the focus of both is on the application of RFID to the hospital supply chain. Figure 1 depicts the process of RFID adoption in healthcare. To research how RFID can help to improve healthcare practices in the hospital supply chain, it is first necessary to recognize the existing problems and issues that drive and impede adoption by this industry. Then different applications can be identified to solve or partially unravel these challenges. As a final result of analyzing the literature, the benefits of and barriers to RFID adoption in healthcare can be identified (see Figure 1).

The literature review was conducted in distinct stages including (1) determining the search strategy and establishing inclusion and exclusion criteria, (2) categorizing the literature, and (3) extracting and analyzing the findings.

Step 1: Literature Identification and Collection

RFID can be applied in a variety of utilization schemes within the hospital setting. Specifically, it can be applied to patient tracking, pharmaceutical tracking, prevention of pharmaceutical counterfeiting, blood tracking, device and supply tracking, and many more uses. Given the potential of each application context to have its own set of benefits and barriers to implementation and rates of adoption, it was decided that the scope of the study should be limited to device and supply tracking. When executing the search, the following terms were used: "Radio Frequency Identification" OR "RFID" OR "RFID standards" AND "supply chain" OR "hospitals" OR "hospital inventory" OR "inventory management OR benefits implementation OR barriers implementation." A mix of databases and online sources was used to compile a set of references covering both academic, peer-reviewed research and practitioner literature.

The following electronic databases and sources were used: ESBCOhost, Academic Search Premier, PubMed, Consumer Health Complete, CINAHL, Health Source: Consumer Edition, and RFID Journal.

Step 2: Literature Categorization

Given the technology- and enterprise-oriented nature of the current study, literature was selected for review on the basis of, but not limited to, the following key areas: technological issues, organizational issues, and organizational impact of technology. Only articles that were written in English were included for review. In an attempt to stay current in research, all journals and references that were older than 12 years (starting from 2000) were eliminated from the search. This literature review yielded 89 references that were assessed for information pertaining to this research project. Thirteen references were used in the introduction and methodology, while 76 sources were used in the results, tables, and discussion.

Step 3: Literature Analysis

In the third step, academic articles and practitioner HIT references were analyzed, and relevant categories were identified and created. The findings are presented in the subsequent sections of the results using the categories of RFID infrastructure in hospitals, RFID adoption in hospitals, benefits of adopting RFID in hospitals, and barriers for RFID adoption in hospitals, following the conceptual framework of Yao et al. (2010) to categorize RFID articles in healthcare.[13.] Table 1 and Table 2 summarize the reviewed articles of these categories, in particular the benefits and barriers. Several references described more than one application, so they are presented in more than one subcategory of each table.

Results

RFID Infrastructure Used in Hospitals

Currently the use of bar codes is widespread among hospitals, but the limitations of this technology are causing those concerned with the healthcare and hospital supply chain to search for other alternatives. Bar codes must be scanned and results coupled with manual cycle counts to reconcile supply usage and on-hand inventory. In addition, bar codes must be scanned at close range, requiring personnel to take time for scanning and relying on human accuracy (Davis 2004).[11] Bar code technology is also limited in the amount of data that can be stored approximately 10 to 12 digits), while RFID tags use a 94-character protocol.[14,15]

Bar codes and associated technology are being replaced with RFID tags and readers in hospitals. The tags are essentially smart labels and, in most cases, have a chip and an antenna as their main components. The radio waves generated during the reading process are able to penetrate many materials and therefore can be employed where tags are not readily visible.[16] RFID enables tracking and monitoring of items over distances that range from about a centimeter to hundreds of meters.[17] RFID can track inventories, mobile equipment, and people in real time as the tagged item travels around the hospital.[18] Tracking of mobile equipment can include wheelchairs, infusion pumps, and blood supplies. Given that hospital personnel fail to locate such mobile assets anywhere from 15 to 20 percent of the time because of misplacement,[19,20] the value of RFID tracking can be seen. Information storage capacity is much less limited than with bar codes, with as much as 2 kilobytes of data stored by a microchip in a RFID tag.[15]

Two types of RFID tags are utilized in RFID systems. The first type, referred to as “passive,” has the ability to store and transmit information, but does not have its own power source. The passive device can only be read by a nearby RFID scanner when the tag is within 18 inches to 30 feet of it, depending on the frequency employed.[21,22] The reader induces a signal from the onboard tag chip that transmits its information. The lack of an integrated power source makes these tags cheaper and more durable in restrictive or physically harsh environments. This type of tag is also more suitable for applications in which tagged items need only be identified at a few or particular locations.[23,24] The other type of tag, referred to as “active,” can transmit information on its own because of its integrated battery. Active tags can continuously transmit and receive signals over long distances, and can store larger amounts of information. Active tags are ideal for applications in which items, such as hospital beds, must be tracked in real time.[21] As an example of each type of tag, consider the uses to which the Memorial Sloan-Kettering Cancer Center in New York has put RFID tags.[24] In addition to tracking several other inventory

items, Sloan-Kettering uses active RFID tags to track infusion pumps. Because the active tags transmit signals, tagged infusion pumps transmit their own location information (i.e., to a reader at a distance), allowing staff to precisely locate and retrieve them as needed. Sloan-Kettering uses passive tags to track and count surgical sponges. Since each tagged sponge would be used once and used in a specific location, the passive tag can be simply read by a nearby reader, thus accounting for each sponge.

In addition to the tags, an RFID system consists of the RFID reader, an antenna, and the software and hardware necessary for communication.[25] This RFID infrastructure can run from $200,000 to $1,000,000 or more for a facilitywide RFID tracking system (see Table 1). Because many hospitals purchase 10 to 20 percent more portable equipment than necessary, RFID systems can help hospitals reduce the need to overpurchase by making it easier to locate equipment when it is needed, resulting in cost reductions in asset inventories (Table 1).

RFID Adoption in Hospitals

Nachtmann and Pohl[59] surveyed 1,381 healthcare supply chain professionals and found that the average provider organization participating in this study was spending more than $100 million each year on supply chain functions, equaling about one-third of their annual operating budget. Pleasant[35] reported that the healthcare industry incurred more than $11 billion in unnecessary costs as a result of inefficiency in supply management. The use of RFID technology can reduce these expenditures by increasing the ability to track and locate equipment, as well as by controlling theft prevention, distribution management, and patient billing (see Table 1).

One area where most hospitals have spent HIT dollars is on Wi-Fi infrastructures, which may be leveraged for RFID-based applications. For about $100,000, a hospital can track its most critical assets by adding RFID to its wireless system.[60] In addition, it has been estimated that a 200-bed hospital using RFID could save $600,000 each year from decreased shrinkage, fewer rentals, deferral of new purchases, improved staff productivity, and enhanced quality improvement. For example, when Advocate Good Shepherd Hospital in Illinois applied RFID to help manage inventory, the annual inventory losses decreased by about 10 percent (see Table 1).[37]

With retail giants such as Wal-Mart and the Department of Defense requiring and mandating that suppliers begin tagging items, and the FDA pushing for pharmaceutical tagging to prevent counterfeiting, the use of RFID technology is slowly making its way into the healthcare market.[61,62] The FDA issued a recommendation that the pharmaceutical industry implement RFID tagging of all drugs by 2007, and recently the FDA approved RFID utilization in the blood supply chain.[30,63]

Benefits of Adopting RFID in Hospital Settings and Healthcare Systems

Since RFID is expected to help reduce costs for hospitals, sales of RFID technology for supply chain applications are expected to grow from $94.6 million to about $1.43 billion in 2019, with more than half of this expense coming mostly from hardware such as tags, readers, and antennas, and the rest from software and services.[64,65] Several interesting examples demonstrate the benefits of the application of RFID technology. The Memorial Sloan-Kettering Cancer Center in New York has been using this technology since 2007 to assess inventory and has expanded its utilization for both asset tracking and workflow by using active RFID to locate wheelchairs and stretchers as well as infusion pumps to determine if they are in use or not (see Table 1).[24]

In a 2010 study in the radiology department of Massachusetts General Hospital, 13 RFID units were installed within two interventional radiology (IR) rooms to store and track inventory assets such as catheters, coils, stents, and other implantable devices. The hospital was able to confirm the need for and cost-effectiveness of RFID technology for supply management within IR and other departments.[27] Because the RFID system has the ability to remove human factors from the clinician workflow as well as eliminate manual cycle counts needed to reconcile usage against actual on-hand inventory, hospitals can achieve increased charge captures, reductions in stock outs, and increased cash collection (Table 1).

An additional benefit is the increased security of patient privacy, which is very important for the future growth of RFID in the hospital industry. Unless a traceable asset could somehow be associated

with a patient and/or the patient's data (e.g., a newborn and the newborn's bed) in violation of HIPAA or other legal and regulatory requirements, RFID asset tracking poses little, if any, threat to patient privacy because assets, not patients, are traced.[43,66] Furthermore, RFID improve privacy protection through the use of universal re-encryption schemes for tags (see Table 1).

Finally, the VA started a $550 million RFID project to equip all 21 of its Veterans Integrated Service Networks, which consists of about 152 medical centers. The RFID system includes a mix of active (mostly Wi-Fi based) and passive tags to be used in asset management, supply management, temperature tracking, and surgical instrument sterilization flow management in addition to "passive RFID tags for the 63,000 cardiac catheterization lab supplies consumed annually by the seven hospitals."[48] (See Table 1.)

Barriers to RFID Implementation in Hospitals

Despite the apparent benefits and strategic relevance of adopting RFID in the hospital supply chain, a study by Yao, Chao-Hsien, and Li (2012) reported that RFID has not been widely adopted in hospitals.[66] As noted above, RFID infrastructure has been reported to cost between $200,000 and $600,000 for a medium-sized hospital or more than $1 million depending on the size of the facility (see Table 2). Regarding tag costs, Hosaka (2004) projected that a 1,000-bed hospital could need to tag 20,000 items daily,[79] while Becker (2004) estimated that an 800-bed hospital could need to tag about 15,000 doses of medication per day.[80] These tags vary in price, with each passive tag costing $0.10 to $0.50 and active tags ranging in cost from $0.50 to $50 each (see Table 2).

System interoperability is a major consideration in the adoption and operation of RFID systems in the supply chain. Examples of healthcare IT systems that need to interoperate with asset tracking systems are medical records, patient billing, and equipment rental. Because RFID-based asset tracking within hospitals is still an emerging technology, these systems are added onto a technology infrastructure with many preexisting systems that interoperate weakly or do not interoperate at all. As is the case with many other technologies, vendors of RFID tracking systems largely ignore these preexisting systems. Thus, this situation increases hospital information technology (IT) complexity and detracts from system utilization (see Table 2).

Another barrier to RFID adoption, which is particular to the US healthcare system and was not described directly in any of the articles reviewed, is competition with other strategic HIT systems and initiatives. Meaningful use is one such initiative. Meaningful use refers to the effort to increase levels and types of use of electronic health records (EHRs) to provide for information exchange among providers and patients, increase quality of care, and achieve better outcomes. Meaningful use is currently being encouraged through an incentive program designed to reward healthcare providers, including hospitals, for their investment and levels of use of HIT for health information exchange (HIE).[3,75] Congress has mandated that the US Department of Health and Human Services develop two sets of regulations, one to guide providers in meeting meaningful use requirements, and the other to guide software developers and vendors in standards for certified EHR systems in hospitals.[81] This HIT/HIE incentive program is the largest pay-for-performance program in US history. The program allocated about $27 billion dollars in incentive payments to eligible healthcare providers.[82] Incentives for adoption of EHRs began in 2011 with Stage 1 of meaningful use, with deadlines in 2011 and 2012 that had to be met to receive financial incentives for the use of electronic prescribing and computerized provider order entry (CPOE), respectively (DHHS 2011).[83] Providers can receive incentives for EHR adoption from the Centers for Medicare and Medicaid Services (CMS) until 2014, with subsequent penalties of 1 percent to 5 percent of reimbursement in place until 2020.

Additionally, hospitals must deal with a mandated deadline of October 1, 2014, for the adoption of International Classification of Diseases, Tenth Revision, Clinical Modification, and International Classification of Diseases, Tenth Revision, Procedure Coding System (ICD-10-CM/PCS) codes instead of the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes currently in use,[76] which has been estimated to cost $2.7 million for large health systems[84] and $425 million to $8 billion in time costs for the healthcare system, including those for system changes, training, and productivity losses.[85,86]All of these changes present financial, organizational, and IT challenges that are primarily realized in cost and time. Thus, they compete directly for capital investment with RFID

adoption. Therefore, few hospitals have been willing and able to adopt RFID systems, and if they have, they have done so predominantly as pilot projects because there is not enough capital, return on investment (ROI), IT staff, and/or time to implement it (see Table 2).

Discussion

The analysis of the recent literature reveals much in the way of progress, given that the healthcare industry, with only 10 percent of hospitals in the United States currently having some kind of RFID system, could produce the critical mass necessary to make adoption of RFID and related systems the rule rather than the exception. However, despite the many apparent benefits, RFID adoption and implementation in the hospital supply chain will have to overcome several significant barriers.

With regard to the problems in healthcare and the needs for RFID in the hospital supply chain, the literature analyzed for this study revealed that hospitals have sought to attain improvements in such areas as hospital productivity, asset management, cost performance, financial performance, and supply chain performance. The benefits derived from the application of RFID to the hospital supply chain are potentially significant. Derived benefits accrue in the form of improvements in hospital productivity, asset management, cost performance, and financial performance; increases in personnel time saving; reduced out-of-stocks; minimized inventory losses; increased efficiency and productivity; and improvements in inventory and equipment processes. Just being able to track an expensive equipment item is itself a benefit and provides assurance of the availability of necessary equipment for various uses and emergencies. In this manner, high-value medical equipment can be located efficiently, using less time, and thus can be better utilized. Benefits such as these have a potentially large associated monetary value, with additional savings attained by providers that can leverage existing infrastructure such as Wi-Fi networks. Consequently, applying RFID can lower the direct and indirect costs in patient care. RFID can also create a safer hospital environment for patients through automation of processes, reduction of errors, and improved quality of patient care, which can enhance overall patient satisfaction. Furthermore, RFID can be used to enhance privacy protection through universal re-encryption of data for protection of patient privacy and HIPAA compliance, which is vital in the hospital environment.

Significant technological and organizational barriers to this technology exist. Adoption and implementation costs and unclear ROI remain significant challenges despite the decreasing cost of the tags and associated equipment. Hospitals must acquire, maintain, and read potentially hundreds of tags of varying cost. Of course, simply adopting RFID does not guarantee a reasonable ROI, and many hospitals are unwilling to invest in technology without a certain or clear return. Given the number of systems acquired by hospitals to address various application areas, the addition of tracking systems utilizing RFID compounds the problems of system interoperability among existing systems. These findings concur with those of Degaspari[24] (2011), who reported that RFID implementation has been slow as hospitals have dealt with budgetary constraints as well as issues of complexity in integration with EHR systems or the hospital Wi-Fi environment.[58] In addition, these barriers have been exacerbated by a lack of standards among producers and consumers of the tags and related hardware and software. The lack of industrywide product identification standards can lead to inconsistent data and problems ranging from supply outages to needless duplicate supply orders.

Two noteworthy gaps that will have to be bridged in the potential adoption of RFID are the ability of other hospital systems to deal with the volume of data generated through RFID use and the redundant data and duplicate readings from RFID data streams. A report from the HDMA Foundation (2006) posits that the volume of data generated by item-level tracking of all prescription products would be huge.[87] Prescription tracking data would of course be generated along with additional data created in device and supply tracking, a significant set of data itself. Concerning data redundancy, several technical approaches that may offer significant improvements to the RFID system are being developed.[88] Although competition from other strategic HIT initiatives was not identified as a barrier by Reyes et al. (2012),[62] the authors of the current study believe that this competition presents a very real barrier, given the findings from the analyzed literature. Furthermore, the American Hospital Association, in response to the ARRA,

recommended a set of alternative hospital meaningful use objectives for 2011–2017, which also included the progressive implementation of bedside medication support using both bar codes and RFID.[89]

Given the previously noted barriers, the authors of this study believe that only a small number of hospitals in the United States will choose to follow those that have already implemented RFID supply chain applications. Because of current cost levels, it is possible that this technology will be temporarily limited to applications in blood centers or for tracking expensive assets and mobile devices. Finally, costs can be drastically reduced and justified if hospital supply chain vendors and the hospital industry engage in proper collaboration to achieve RFID standardization.

Limitations

This research study is not without limitations. References and sources included studies conducted in Europe, Taiwan, Canada, and the United States, which have distinct differences in the pace of RFID adoption and barriers for RFID implementation. Empirical studies on the utilization of RFID in the hospital supply chain were limited. Finally, publication and researchers' bias cannot be ruled out.

Conclusion

RFID has shown great impacts on the hospital supply chain. Although some concerns regarding this technology remain, particularly in the cost of its implementation, there is a general conviction that hospitals, by deploying RFID in the supply chain, can significantly reduce costs, which has been the main barrier for RFID adoption due to uncertain ROI. Competing strategic HIT technologies for hospitals and federal mandates for EHR adoption have also delayed massive RFID implementation. If barriers to implementation can be overcome, RFID will represent a revolution in HIT.

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Table 1

Benefits of Radio-Frequency Identification (RFID) Technology in the Hospital Supply Chain

Benefit	Details
Financial benefit	• Increase in charge capture and increase in cash collection (Menachemi et al. 2006[26]; Byers et al. 2011;[27] Qu et al. 2011[28]) • Recovery of investment from implementation with 30 months in large hospitals' transfusion centers[29] (Briggs 2009) • Significant return on investment in a blood center's operations through labor saving and error reduction[30] (Hohberger et al. 2012)
Overall decreased supply chain expenditure	• Cost reductions in asset inventories[31,](Fisher and Monahan 2012; Kamel Boulos and Berry 2012)[32] • Improved business processes and workflow, decreased equipment cost, improved inventory management, and decreased operating cost (CEJA 2007[33]; Kumar et al. 2009[34]; Pleasant 2009[35]) • Improved equipment utilization (Britton 2007[36]; Qu et al. 2011[28]) • Decrease in asset overpurchasing (Kamel Boulos and Berry 2012[32]) • Less shrinkage, fewer rentals, deferral of new purchases, improved staff productivity, and enhanced quality improvement (Glabman 2004[37]; Buyurgan et al. 2009[38]; Swedberg 2010[39]; Çakici et al. 2011[40]; Bendavid and Boeck 2011[41])
Supply and asset tracking	• Improved traceability and visibility of products and processes (EndoNurse 2006[42]; Butters 2006[17]) • Savings with real-time tracking of mobile assets (Davis 2004[11]; Lin 2009[18]; Degaspari 2011[24]; Bunduchi et al. 2011[43]; Segovis 2012[44]) • Decreased failure to locate mobile assets and equipment (IDTechEX 2006[19]; Li et al. 2006[45]; Madrid et al. 2012[20]) • Tracking and management of the utilization of high-cost devices and supplies (Health Data Management 2007[46]; Bendavid and Boeck 2011[41])
Security and safety	• Monitoring of temperature of perishable and heat-sensitive items (Swedberg 2012 "Children's,"[47]; Swedberg 2012 "Veterans"[48]) • Tracking of blood samples and monitoring of compatibility of blood transfusions (Carlisle 2012)[49] • Reduction of morbidity and mortality of patients receiving transfusions (Briggs et al. 2009)[29] • Tracking of pediatric equipment such as beds and pumps in which the infant is included in the asset tracking (Dobson et al. 2012)[50] • Privacy protection through re-encryption of data (Saito et al. 2004[51]; Chao et al. 2007[52])
Efficiency and productivity	• Reduction in labor required to track the temperature of perishable and nonperishable supplies and devices (Swedberg 2012 "Children's,"[47]; Swedberg 2012 "Veterans"[48]) • Improvement in operating room utilization efficiency (Chao et al. 2007[52], Liu et al. 2011[53]). • Tracking of waste-disposal materials (Chao et al. 2007[52])

Leveraging of existing network infrastructure	• Lowered cost by building on existing or new Wi-Fi networks (Scott 2006[54]; Sarac et al. 2010[55]; Ekahau Inc. 2012[56])
Improved data quality	• More data on both types of RFID tags (Pandey 2010[57]) • Decrease in stock overcounts (Revere et al. 2010[58]) • Better data concerning equipment availability (Swedberg 2010[39])

Table 2

Barriers to Radio-Frequency Identification (RFID) in the Hospital Supply Chain

Barrier	Details
Cost/ROI challenges	• Passive tag cost of $0.10 to $0.50 each; active tag cost of $0.50 to $50 (Barcoding Corporation 2011)[67] • Expensive RFID infrastructure to be implemented in the hospital setting (Page 2007[68]; Fisher and Monahan 2008[69]; Ngaia et al. 2008[25]; Martinez Perez et al. 2012[70]) • Increased networking costs (Fisher and Monahan 2008[69]; Krohn 2008[71]) • High cost of implementation (Kumar et al. 2009[34]) • Unclear ROI (Bunduchi et al. 2011[43]; Yao et al. 2012[66]) • Shortage of comprehensive information to evaluate RFID implementation cost and ROI for assessment of adoption (Chao et al. 2007[72])
Interoperability	• Lack of RFID interoperation with existing hospital systems (Fisher and Monahan 2008[69]) • Lack of international standards between Europe and the United States (Sarac et al. 2010[55]) • Lack of interoperability of existing hospital systems (Fisher and Monahan 2012[31])
Location accuracy	• Limited location accuracy (Krohn 2008[71]; van der Togt et al. 2011[73]; Kamel Boulos and Berry 2012[32]; Okoniewska et al. 2012[74])
Organizational challenges	• Resistance to change or failure to get buy-in from personnel (Attaran 2007[14]; Revere et al. 2010[58]; Fisher and Monahan 2012[31])
Competing strategic healthcare informatics systems	• Implementation of electronic prescribing, CPOE, EMR/EHR systems, HIE, ICD-10-CM/PCS, business analytics/intelligence, tablet integration, new healthcare business models, and IT privacy and security (CMS, 2013 "EHR[75]," 2013 "ICD-10"[76]; US Department of Health and Human Services 2010[77], 2011[78])

Figure 1

Research Framework